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Comparison of forecast estimates of seabed subsidence of the Yuzhno-Kirinskove field

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Abstract. The geodynamic consequences of the field development process include the subsidence of the earth's surface. Monitoring of deformations in offshore fields is difficult and it is necessary to evaluate them by various methods. It is important to investigate how much the calculated amplitude of the seabed subsidence is reduced by taking into account changes in the porosity and compressibility of the pore space with a decrease in reservoir pressure. The analysis of changes in the petrophysical parameters of the reservoirs of the Daginsky horizon during the projected development of the Yuzhno-Kirinskoye hydrocarbon field for depletion and a decrease in formation pressure by 10 MPa showed that the porosity decrease will be 0.038 absolute percent, the compressibility of the pore space will decrease by 0,08 10⁻³ 1/MPa. With the help of the Petrel software, changes in the thickness of the productive layer from 80 to 120 cm were obtained, which can be taken as an estimate of the seabed subsidence in the area of the field. The application of the genetic model of the deformable formation by Kuzmin Yu showed that the maximum amplitude of the seabed subsidence to be 101 cm. Comparison of these estimates of the seabed subsidence indicates their proximity. Taking into account the dynamics of tectonophysical and petrophysical characteristics due to the long-term development of hydrocarbon deposits significantly changes the intensity of the deformation state of the rock mass and the earth's surface above the field.

1. Introduction

Long-term development of oil and gas fields is often carried out in conditions of reducing reservoir pressure. This often happens during the development of gas fields, since they, unlike oil fields, practically do not use reservoir pressure maintenance. As is known, the most well-known form of manifestation of negative geodynamic consequences accompanying the process of reducing reservoir pressure is extensive subsidence of the earth's surface [1–7]. For example, relative deformations can reach threshold values of 10^{-3} , which are designated as dangerous in regulatory documents [8, 9], with typical field sizes of 50-100km and accumulated subsidence of several meters. It is extremely important to illustrate this by the example of offshore fields, since setting up full-scale monitoring of deformations, is impossible at such objects for natural reasons. In this situation, model assessments is both an element of the design of observation systems and a basic link in the interpretation of monitoring results, at the same time. In order to determine the optimal configuration of the observation system and its metrological characteristics, it is necessary to evaluate the level of possible deformations (the amplitude of displacements and their spatial distribution) by several different methods. It is important to investigate the question of how much such decreases in poroelastic parameters, especially the compressibility coefficient of the pore space, reduce the final, estimated amplitude of the subsidence of the earth's surface.

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2. The results of experimental studies

The results of experimental studies using the method of modeling reservoir conditions [10] were analyzed for about 240 samples of sandstones that had an open porosity of 2.9–33.4 % in atmospheric conditions [11–13]. The results showed that the dependence of the average value of the porosity (*m*) on the effective pressure (P_{ef}) can be described with a high degree of confidence (0.99) (figure 1a) by the power dependence (1):

$$m = 22.604 \cdot P_{ef}^{-0.020} \tag{1}$$

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An increase in the effective pressure (reduction of reservoir pressure) by 10 MPa (from 37 MPa to 47 MPa) during reservoir development will lead to a decrease in porosity from 20.967 % to 20.929 % or by 0.038 absolute percent of porosity.



Figure 1. Changes in porosity (a) and compressibility (b) of the pore space with an increase in the effective pressure.

It is revealed that the dependence of the average value of the compressibility coefficient of the pore space (C_{por}) on the effective pressure (P_{ef}) (figure 1b) with a high degree of confidence (0.97) is described by the power equation (2):

$$C_{por} = 5.15 \cdot 10^{-4} \cdot P_{ef}^{-0.321} \tag{2}$$

An increase in the effective pressure during reservoir development from 37 to 47 MPa, i.e. by 10.0 MPa, will lead to a decrease in the average compressibility of the pore space from $1.56 \cdot 10^{-3}$ to $1.48 \cdot 10^{-3}$ 1/MPa or on $0.08 \cdot 10^{-3}$ 1/MPa, which means a decrease in the compressibility of the pore space by 5.3 % after reducing the reservoir pressure by 10 MPa relative to its magnitude of 37.0 MPa at the beginning of development.

3. The object of research

The Yuzhno-Kirinskoye oil and gas condensate field is located on the north-eastern shelf of Sakhalin Island at a distance of 35 km from the coast, the sea depth at the field varies in the range of 110-320 m. Drilling of eight exploration wells revealed the oil and gas content of slightly inclined layers of the Daginsky horizon of the Miocene, which is represented by sandstones, siltstones and clays with a thickness of up to 200 m [14–16]. The location of wells and blocks of the Yuzhno-Kirinskoye field is described in [14]. The values of the weighted average porosity for the wells of the field are on average 20–23 %. The main task of this work was to determine the nature and magnitude of changes in the pore space during the development of reservoirs of the Daginsky horizon and to estimate the magnitude of possible surface subsidence.

4. Methods and results of geological and mathematical modeling of the process of reducing reservoir pressure

In the hydrodynamic modeling programs PETREL, ECLIPSE, VIP Landmark and others, the problem of possible subsidence calculation is solved within the framework of the theory of elastic deformations, taking into account the distribution of reservoir and elastic properties of the reservoir in space. At the same time, in the first approximation, it is assumed that changes in porosity occur only in the reservoir due to a decrease in reservoir pressure. Considering the fact that the overlying layers are not subjected to dynamic influence, the displacement of the roof of the productive layer is usually assumed to be equal to the displacement of the seabed surface, taking into account the distribution in space of its filtration-capacitive and elastic properties and the value of the reduction in reservoir pressure.

The initial geological model before the start of development reflects the state of the productive reservoir at the time of starting the development, i.e. at an effective pressure of 37 MPa. A further increase in the effective pressure to 47 MPa accompanies the process of reducing the reservoir pressure by 10 MPa, and geological and mathematical modeling allows us to take into account changes in physical parameters, in particular the porosity of reservoirs, during the development of a field for depletion. The map of the effective thicknesses of the productive part of the reservoir was reconstructed, but already at a porosity value of 47 MPa. As a result, a map of the effective thicknesses of the productive reservoir was obtained taking into account the reduction of the volume of the pore space and the volume of the reservoir itself during development without maintaining the reservoir pressure.

Using the calculator built into the Petrel software, we obtained the difference in effective thicknesses (figure 2), which can be taken as the value of the change in the thickness of the productive layer. Assuming that their thickness and porosity do not change in the overlying strata, the areal distribution of the difference in effective thicknesses can be taken as the distribution of the value of the seabed subsidence in the field development zone.



Figure 2. A map of changes in the effective reservoir thicknesses after a decrease in reservoir pressure by 10MPa (P_{ef} 47MPa).

Modeling with a genetic model of a deformable reservoir [17, 18] was successfully tested at a number of hydrocarbon deposits, including offshore and underground gas storage facilities [4, 6, 7, 19]. The priority in choosing this model is determined by a number of fundamental factors described in the works

[20, 21]. As is known, the formula for calculating, for example, the vertical displacements of the earth's surface (Uz) consist of the product of two factors:

$$U_{\mathcal{Z}} = F \cdot G \tag{3}$$

The physical factor F in (3) includes such parameters as porosity m, compressibility of the pore space C_{por} , as well as the change in reservoir pressure ΔP_{por} . The geometric factor G, in formula (3), takes into account the geometric dimensions of the layers taken on the basis of geological profiles along and across of the field [14, 15]. The productive layers were modeled by the prism with the following characteristics: width 2a (40 km), length 2b (80 km), depth of the upper d (2790 m) and lower D (2850 m) boundaries of the effective gas-saturated part of the formation and the average depth of the formation H (2820 m).

The average values of porosity and compressibility of the pore space at a reservoir pressure of 27 MPa at the beginning of development were used as initial values: m = 20.967 % and $C_{por} = 1.56 \cdot 10^{-3}$ 1/MPa. To calculate the subsidence, a scenario was adopted that the reservoir pressure would decrease by $P_{por} = 10$ MPa. At the same time, the following values will be obtained: m = 20.929 %, $C_{por} = 1.48 \cdot 10^{-3}$ 1/MPa. The vertical displacements were constructed taking into account changes in the porosity and compressibility of the pore space during the development of the field with a decrease in pore pressure to 17 MPa (figure 1a and 1b). For comparison and visual illustration of accounting the results of physical modeling of changes in the petrophysical parameters of reservoirs during development, displacement curves are shown, which have been obtained without taking into account changes in the porosity and compressibility of productive rocks (figure 3).



Figure 3. Modeling of the distribution the seabed vertical displacement for the developed reservoir with a decrease in reservoir pressure from 27 to 17 MPa (ΔP_{por} -10 MPa). 1 – subsidence at the values of porosity and compressibility at the time of the beginning of field development; 2 – subsidence taking into account changes in porosity and compressibility during decrease in reservoir pressure.

5. Discussion

The analysis of changes in petrophysical parameters of the oil and gas saturated reservoirs of the Daginsky horizon of Miocene age during the projected development of the Yuzhno-Kirinskoye hydrocarbon field for depletion and a decrease in fluid pressure in the reservoir by 10 MPa showed that the porosity coefficient will decrease by 0.038 absolute percent, the compressibility of the pore space will decrease by $0.08 \cdot 10^{-3}$ 1/MPa, which means a decrease in the compressibility of the pore space by 5.3 % relative to its value at the beginning of development.

The geological models constructed using the Petrel software reflect the geological structure and spatial distribution of the porosity of the productive reservoir both at the time of the start of development at an effective pressure of 37 MPa, and with a decrease in reservoir pressure by 10 MPa. They include maps of the distribution of effective thicknesses, maps of the distribution of the porosity of productive layers, which allowed, in the first approximation, to take into account changes in physical parameters, in particular the porosity of reservoirs, during the development of the field for depletion, accompanied by an increase in the effective pressure to 47 MPa. The difference in effective thicknesses at effective pressures of 37 and 47 MPa was taken as the value of the change in the thickness of the productive reservoir. Considering that the porosity and reservoir pressure of the fluids of the overlying layers do not change, their thickness also does not change, the areal distribution of the difference in effective thicknesses can be taken as the distribution of the magnitude of the seabed subsidence in the field area. Estimates of the seabed subsidence ranging from 0.2 to 1.34 meters were obtained. The most common subsidence values are in the range from 0.8 to 1.2 m. The maximum value of 1.34 m is found only in some local places.

The results of the application of the genetic model of the deformable formation have shown that when the reservoir pressure decreases by 10 MPa, the maximum amplitude of the seabed subsidence according to the data obtained at the beginning of development ($P_{ef} = 37$ MPa) will be 101 cm. This value is quite close to the value of 134 cm obtained by modeling using the Petrel software, but less due to taking into account the genesis of the anticlinal fold formed by tectonic forces. Applying the genetic model, we also tried to use data on the compressibility of the reservoir at $P_{ef} = 47$ MPa, which allowed us estimating already at a value of 95 cm. This allowed us to conclude that the difference in estimates, taking into account changes in compressibility during development and without it, is very significant. Thus, with a decrease in reservoir pressure by 10 MPa, it will be 6.0 cm, but the discrepancy by the end of development (a decrease in reservoir pressure by about 27–28 MPa) can be significantly larger, about 20-30 cm.

6. Conclusion

The comparison of the estimates of the seabed subsidence with a decrease in reservoir pressure by 10 MPa, performed using the Petrel software and the genetic model of the deformable formation, indicates their proximity. At the same time, taking into account the genesis of the anticlinal fold formed by tectonic forces makes it possible to slightly reduce the assessment of the seabed subsidence.

The conducted studies have convincingly demonstrated that taking into account the dynamics of tectonophysical and petrophysical characteristics due to the long-term development of hydrocarbon deposits significantly changes the intensity of the deformation state of the rock mass and the earth's surface above the deposit and, consequently, the idea of the level of geodynamic risk of oil and gas complex objects.

References

- Kuzmin Yu O 2002 Fundamental basis of new technologies of oil and gas industry Modern [1] geodynamics of abnormal subsurface induced by development of oil and gas fields (Moscow, GEOS) pp 418-427
- [2] Zhukov V S, Kuzmin Yu O 2003a Physical modeling recent geodynamic processes Mining informational and analytical Bulletin 5 pp 71–77

- [3] Zhukov V S, Kuzmin Yu O 2003b Gas resources of Russia in XXI century Modeling of deformation and seismic processes in the development of hydrocarbon deposits (Moscow, VNIIGAZ) pp 456–469
- [4] Zhardetsky A V, Zhukov V S, Moiseev P V, Kuzmin Y O 2003 Application of geologicalmathematical modeling for monitoring of geodynamic processes in the operation of UGS *Karotazhnik* 102 pp 67–76
- [5] Zhukov V S 2010 Assessment of changes in the physical properties of reservoirs caused by the development of oil and gas fields *Mining information and analytical bulletin* **6** pp 341–349
- [6] Kuzmin Yu O, Descherevsky A V, Fattakhov E A, Kuzmin D K et al 2018 Inclinometric observations at the Y Korchagin field *Geophysical processes and biosphere* **53** 3 pp 31–41
- [7] Kuzmin Yu O, Descherevsky A V, Fattakhov E A, Kuzmin D K, et al 2019 Analysis of the results of deformation observations by the inclinometer system at the V Filanovsky field *Geophysical processes and biosphere* 18 4 pp 86–94
- [8] Kuzmin Yu O 2019b Recent Geodynamics: from Crustal Movements to Monitoring Critical Objects *Physics of the Solid Earth* 55 1 pp 65–86
- [9] Kuzmin Yu O 2020 Actual issues of the use of geodetic measurements in geo-dynamic monitoring of oil and gas complex objects *Bulletin of SGUGIT* **25** 1 pp 43–54
- [10] Zhukov V S, Lyugay D V 2016 Determination of filtration-capacitance and elastic properties and electrical parameters of rock samples when modeling reservoir conditions (Moscow: VNIIGAZ) 56 p
- [11] Zhukov V S, Ivanov P Yu 2015 Changes in the physical properties of the reservoir as a result of an increase in the effective pressure during the development of the field (modeling on the example of the Yuzhno-Kirinskoe field) *Vesti gazovoi nauki* 24 4 pp 144–148
- [12] Zhukov V S, Churikov Yu M, Motorygin V V 2017 Changes in the structure of the pore space of the reservoirs of the Daginsky horizon when modeling reservoir conditions *Vesti gazovoi nauki* 31 3 pp 238–246
- [13] Zhukov V S, Kuzmin Yu O, Semenov E O 2018 Dynamics of physical properties of reservoirs in the development of oil and gas fields *Vesti gazovoi nauki* **12** 1 pp 82–99
- [14] Dzyublo A D, Shnip O A, Altukhov E E, Tsherbakova A Iu 2016 Lithological-geophysical characteristics for the Daginsky horizon rocks of the Yuzhno-Kirinskoe field *Oil and gas Geology* 4 pp 39–46
- [15] Rybalchenko V V, Gogonenkov G N, Parasyna V S 2014 Formation environments for the Yuzhno-Kirinskoe field on the Sakhalin shelf *Oil and gas Geology* 4 pp 42–52
- [16] Aulova D Yu, Zhukov V S, Motorygin V V et al 2015 Assessment of the influence of clay content on the filtration and reservoir properties of the collector *Gas industry* **721** 4 pp 29–32
- [17] Kuzmin Yu O 1999 Recent geodynamics and evaluation of geodynamic risk in subsoil resources (Moscow: Publ. "AEN") p 220
- [18] Kuzmin Yu O 2010 Once again about the assessment of the subsidence of the bottom of the water area in the case of the development of the senomanskoe reservoir of one gas field *Mine Surveying Bulletin* **75** 1 pp 53–60
- [19] Zhukov V S, Kuzmin Yu O, Poloudin G A 2002 Evaluation of the processes of subsidence of the earth's surface in the development of gas fields (for example, the North Stavropol field *Geology, Geophysics and development of oil and gas fields* 7 pp 54–57
- [20] Abramyan G O, Kuzmin D K, Kuzmin Yu O 2018 Solution of inverse problems of recent geodynamics of subsoil in hydrocarbon fields and underground gas storage facilities *Mine Surveying Bulletin* 125 4 pp 52–61
- [21] Abramyan G O, Kuzmin D K 2019 Modeling of gradients of displacements of the Earth's surface in the developed oil and gas fields *Mine Surveying Bulletin* **132** 5 pp 56–62